Technical Issues with Monoplace Chamber Air Breaks

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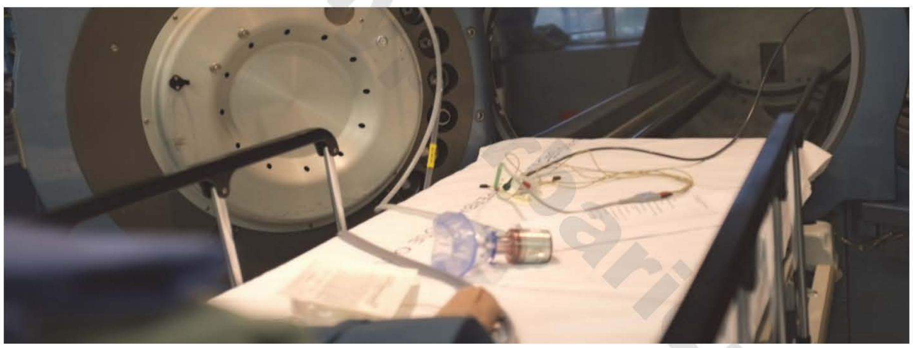
INTRODUCTION

Air breaks are incorporated into hyperbaric treatments to help reduce the risk of central nervous system oxygen toxicity. Tolerance of oxygen is variable among patients, so it is an individualized medical decision whether or not air breaks are indicated. The hyperbaric physician orders the frequency and duration of air breaks. An unplanned air break may also be given if the patient exhibits signs of oxygen toxicity (e.g. twitching, visual disturbances, or auditory disturbances). When air breaks are ordered, it is usually the chamber operator's responsibility to ensure the equipment is set up and working properly. This article discusses the technical issues involved in delivering air breaks.



A monoplace chamber is typically compressed with oxygen, allowing the patient to receive hyperbaric oxygen without a breathing device. In order to administer air breaks, an entire air break assembly must be added to the monoplace chamber. The air break assembly consists of a medical air source, regulator or flow meter, hoses, and a breathing device. The device may be a constant flow mask, demand mask, or demand mouthpiece. There is typically a specific penetrator on the monoplace chamber to allow the air break gas supply through the chamber wall. Air break assemblies can be divided into two categories: demand and constant flow. The two operate differently and have different requirements in order to work properly.

OBJECTIVES

At the completion of this article, the reader will be able to:

1) Identify the pressure requirement for a demand air break assembly
2) Calculate the flowmeter error in a constant flow air break assembly
3) Identify the flow requirement for an air break with a non-rebreather mask

ACRONYMS USED IN THIS ARTICLE:

ATA	Atmospheres absolute (measurement of pressure)
CO_2	Carbon dioxide
LPM	Liters per minute (measurement of flow)
mmHg	Millimeters of mercury (measurement of pressure)
NRB	Non-rebreather mask
pO_2	Partial pressure of oxygen
psig	Pounds per square inch gage (measurement of pressure)

DEMAND AIR BREAK ASSEMBLIES

A demand air break assembly employs a demand regulator to convert the pressurized air source to a suitable flow for the patient to breathe. The demand regulator is located inside the chamber, close to the patient. Gas does not flow through the regulator until the patient inhales. The negative pressure of inhalation opens the valve to allow flow. Gas flow stops when each inhalation stops. The pressure delivered to the patient is nominal, because a demand regulator (just like a SCUBA diving regulator) delivers flow at almost the same pressure as the chamber. The pressure difference is so small, it is measured in centimeters of water pressure (1 cm H_2O = 0.014 psig). Because gas is flowing only during inhalation, a demand regulator conserves the gas supply.

Demand regulators require the supply pressure to be within a certain range. The demand regulator supplied by most monoplace chamber manufacturers requires 40-60 psig more than the pressure inside the chamber. Because the maximum pressure inside the monoplace chamber is 29.4 psig, supply pressure of 70 psig should allow the demand air break to function at all chamber pressures (see Table 1).

The patient interface in a demand air break assembly is typically a mask, but may be a mouthpiece instead. When a mask is used, it must seal to the patient's face without leaks. If the mask is poorly fitted, there will be an inbound leak during inhalation; and there may not be enough negative pressure during inhalation to open the valve inside the regulator (i.e. gas will not flow through the regulator).

DIFFICULTIES WITH DEMAND AIR BREAKS

Air breaks with a demand mask require the patient to hold the mask tightly to his/her face. This may be physically difficult for some patients. There is a small amount of inspiratory resistance when the patient breathes in and a small amount of expiratory resistance when the patient breathes out. This resistance may be uncomfortable and/or may require patients who breathe gently to exert more effort.

Because a tight fitting mask is important, different size options may be necessary to fit a variety of patients. In order to get a better fit, some hyperbaric facilities replace the standard mask with an air cushion anesthesia mask (with a syringe port on the air cushion). The air in the cushion is replaced with water, preventing the mask from flattening when the chamber is pressurized. To avoid the problem of mask fit, some hyperbaric facilities use a respiratory mouthpiece instead of a mask. When a mouthpiece is used, the patient must breathe through the mouth (instead of the nose) in order to receive the air break. The addition of a nose clip can prevent nose breathing.

Because of the hardness and shape of the demand regulator, it can scratch the inside wall of the chamber. This can occur if the regulator bumps or rubs the chamber wall during the treatment. It can also occur if the regulator is lying between the chamber wall and the patient tray when the tray is slid in or out of the chamber. The valve should be in the patient's hand or on the patient's chest before sliding the tray in or out.

What if a demand mask is used improperly?

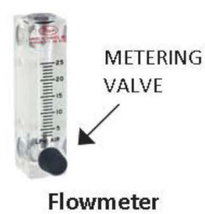
Because of the issues with mask fit and the required inspiratory effort, it is possible for a patient to hold the mask up to the face, but breathe around the mask and not cause the valve to open. In this case, the patient is not receiving an air break. If CO_2 collects in the mask during exhalation, the patient may have an elevated level of CO_2 with each inhalation. Elevated CO_2 increases the risk of central nervous system oxygen toxicity.

INFECTION CONTROL WITH DEMAND AIR BREAKS

The mask or mouthpiece in a demand air break assembly should be patient-specific. When a patient exhales, his/her exhalation goes into the mask and into the body of the demand regulator, contaminating them both. The hyperbaric facility should do one of the following: purchase multiple demand regulators and make them patient-specific; sterilize the demand regulator after each use; or install a patient-specific filter between the demand regulator and the patient. Filters are the most economical solution to this infection control issue. If there is a patient-specific filter in place, the supply hose and demand regulator may be shared between patients (if they are wiped down between uses).

CONSTANT FLOW AIR BREAK ASSEMBLIES

A constant flow air break assembly employs a metering valve to convert the pressurized air source to a flow for the patient. A metering valve allows for small adjustments to the flow. The metering valve may be part of a flowmeter. The patient interface is typically a NRB because it is readily available, inexpensive, and disposable. A NRB will deliver 60%-80% of the breathing gas supplied. Fit of the mask, depth of inspiration, and the LPM of gas flow all effect the percentage of gas supplied by a NRB. Fifteen LPM is generally accepted as the proper flow for a NRB to deliver up to 80% of the supply gas.[1] Because of the variations in percentage of gas delivered, a NRB is not recommended for oxygen delivery in hyperbaric chambers. However, when used for air breaks in monoplace chambers, a NRB can significantly reduce the patient's inspired pO_2. If the NRB delivers 80%, the pO_2 during the air break is approximately ⅓ of the pO_2 during the oxygen breathing period (see Table 2). Because gas is flowing during the entire air break, a constant flow air break consumes more gas than a demand air break.



Flowmeter

Why is a NRB only 60-80%?

A NRB is not designed to seal to the face, so some amount of inbound leak is expected during inhalation. When the flow to the NRB is 15 LPM, it should be enough to meet the average inspiratory demand of approximately 6-10 LPM (in a normal adult). During each inhalation however, the peak flow rate is between 400 and 700 LPM for a fraction of a second. Therefore, part of each breath is supplied by the 15 LPM flow, part from the NRB reservoir bag, and part *leaks in around the mask, diluting the gas. Patients who inhale more deeply (typically larger patients) will have more inbound leak and more dilution. Increasing the actual flow up to 30 LPM can reduce the inbound leak.*

FLOWMETER ERROR

When the hyperbaric chamber is pressurized, the air break flowmeter reading is inaccurate because of the density of the gas in the chamber. The error is described by Graham's Law. The formula for Graham's Law is:

$$\text{Actual Flow} = \text{Flowmeter Setting} \div \sqrt{\text{Chamber ATA}}$$

The flowmeter setting you want can be calculated by re-arranging Graham's Law to read:

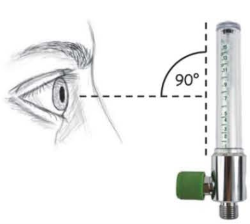
$$\text{Flowmeter Setting} = \text{Desired Actual Flow} \times \sqrt{\text{Chamber ATA}}$$

The square root of the chamber ATA is: 1.41 @ 2.0 ATA; 1.58 @ 2.5 ATA; 1.73 @ 3.0 ATA.

To achieve an actual flow of 15 LPM at 2.0 ATA, the flowmeter must be set at approximately 21 LPM. To achieve an actual flow of 30 LPM at 2.0 ATA, the flowmeter must be set at approximately 42 LPM. At higher chamber pressures (e.g. 2.5 ATA, 3.0 ATA), the flowmeter settings would be even higher to achieve the desired flow (see Table 3).

What is the proper way to read a flowmeter?

The ball on the flowmeter indicates the amount of flow going out of the flowmeter. To read the meter accurately, your eyes should be perpendicular to the flowmeter scale (not at an upward or downward angle). The horizontal line that is even with the widest point of the ball indicates the flow. To put it simply, look straight at the meter and read where the center of the ball is.



DIFFICULTIES WITH CONSTANT FLOW AIR BREAKS

Unlike demand air breaks, there is no inspiratory or expiratory resistance with constant flow air breaks, making them generally more comfortable and easier for patients to use. However, the constant high flow of gas can blow out around the mask and may blow into the patient's eyes. If the flow is reduced to minimize gas blowing into the patient's eyes, the percentage of supply gas delivered by the NRB is also reduced.

If the air break assembly has a metering valve but no flowmeter, the chamber operator must estimate the flow to the NRB. When the actual flow to the NRB is approximately 15 LPM, each patient inhalation should consume approximately ⅓ of the gas in the NRB reservoir bag, which should refill during exhalation. If the reservoir bag stays full during inhalation, the flow is higher than 15 LPM. If the reservoir bag completely deflates during inhalation, there is not enough flow to meet the patient's inspiratory demand.

A NRB has a small metal clip located at the bridge of the patient's nose. The clip can be pinched to create a tighter fit at the top of the mask. During loading and unloading of the patient, the metal clip can scratch the inside wall of the chamber. This can occur if the NRB is lying between the chamber wall and the patient tray when the tray is slid in or out of the chamber, or if the metal clip comes off the NRB. Some hyperbaric facilities remove the metal clip for this reason, giving up the ability to improve the fit of the mask.

INFECTION CONTROL WITH CONSTANT FLOW AIR BREAKS

A NRB (or any other type of mask used for a constant flow air break) should be patient-specific. There should be no shared components. The inside of the mask can be wiped down after each use and stored for the same patient to use during the subsequent treatment.

CHECKLISTS

Each hyperbaric facility should have a daily startup checklist for the facility and a pre-treatment checklist for each patient treatment. When air breaks are used, there are items that should be included on both the facility startup checklist and the pre-treatment checklist.

Daily Startup Checklist:

- Availability of adequate medical air supply. If an air cylinder is used, is there enough pressure in the cylinder to last the day? If multiple cylinders are used, are there enough full cylinders to last the day?
- Adequate air supply pressure. For a demand regulator, the air pressure to the chamber should be 70 psig. For a flowmeter, 50 psig is adequate.
- Adequate supply of equipment for the day: masks, demand regulators (if applicable), filters (if applicable), hoses.

Pre-treatment Checklist:

- Air break assembly set up properly.
- Air break assembly functioning properly.

How long will a cylinder of air last?

In order to answer the question, you must know the total amount of gas in the cylinder when it is full and how much gas is consumed per minute. A typical air cylinder is a "K" cylinder (51 inch tall x 9 inch diameter) which contains 244 cubic feet (6900 liters) of gas when full (2200 psig). Although a full K cylinder has 2200 psig, it must be changed out when the pressure drops below 200 psig. Therefore, a full cylinder has approximately 2000 psig of usable gas (6300 liters). The amount of gas consumed is different with demand and constant flow air breaks.

For a demand air break, the gas consumed per minute varies depending on how deep and how fast the patient is breathing. The calculation is: (tidal volume of each breath) x (# of breaths per minute) x (chamber pressure in ATA). A single K cylinder will support 200-300 minutes of demand air breaks, depending on chamber pressure (see Table 4).

For a constant flow air break, the gas consumed per minute is set by the chamber operator. The calculation is: (actual flow at chamber pressure) x (chamber pressure in ATA). A single K cylinder will support 70-200 *minutes of constant flow air breaks, depending on chamber pressure and the amount of flow you select (see Table 4).*

To look at it another way, how long of an air break can I get out of each 100 psig in a cylinder? For a demand air break, you should get at least 10 minutes, depending on chamber pressure (see Table 5). For a constant flow air break, you should get at least 3.5 minutes, depending on chamber pressure (see Table 5). Before a treatment begins, it is important to know if there is enough air supply for any air breaks that might be needed (either planned or unplanned).

REFERENCES

1. Garcia JA, Gardner D, Vines D, Shelledy D, Wettstein R, Peters J (October 2005). "The Oxygen Concentrations Delivered by Different Oxygen Therapy Systems". Chest Meeting 128 (4): 389S–390S.

TABLE 1: SUPPLY PRESSURE REQUIREMENT FOR DEMAND REGULATOR

Chamber Pressure (ATA / psig)	Demand Regulator Requirement (psig)	Minimum Supply Pressure Required (psig)
1.0 / 0.0	40.0	40.0
2.0 / 14.7	40.0	54.7
2.5 / 22.0	40.0	62.0
3.0 / 29.4	40.0	69.4

TABLE 2: OXYGEN REDUCTION ACHIEVED DURING NON-REBREATHER AIR BREAK

Absolute Pressure (ATA)	Inspired pO_2 in Oxygen	Inspired pO_2 in Air	Inspired pO_2 with Non-rebreather Air Break (delivering 80%)
2.0	1520 mmHg	318 mmHg	558 mmHg
2.5	1900 mmHg	397 mmHg	698 mmHg
3.0	2280 mmHg	477 mmHg	837 mmHg

TABLE 3: FLOWMETER SETTING AT VARIOUS CHAMBER PRESSURES

Chamber Pressure (ATA)	$\sqrt{\text{Chamber ATA}}$	Flowmeter Setting	
		to achieve 15 LPM actual flow	to achieve 30 LPM actual flow
1.0	1.00	15.0	30.0
2.0	1.41	21.2	42.4
2.5	1.58	23.7	47.4
3.0	1.73	26.0	52.0

TABLE 4: DURATION OF A SINGLE K CYLINDER FOR AIR BREAKS

Chamber Pressure	Demand Air Break		Constant Flow Air Break	
	Gas Consumed Per Minute*	Total Air Break Minutes Available	Gas Consumed Per Minute of Air Break (15 LPM / 30 LPM)**	Total Air Break Minutes Available (15 LPM / 30 LPM)**
2.0 ATA	20 LPM	315 min	30 liters / 60 liters	210 min / 105 min
2.5 ATA	25 LPM	252 min	37.5 liters / 75 liters	168 min / 84 min
3.0 ATA	30 LPM	210 min	45 liters / 90 liters	140 min / 70 min

* Based on tidal volume of 0.5 liters per breath and 20 respirations per minute.

** Actual flow after compensating for flowmeter error.

TABLE 5: AIR BREAK MINUTES AVAILABLE PER 100 PSI OF CYLINDER PRESSURE

Chamber Pressure	Demand Air Break (0.5 Tidal Volume/20 Resps per Min)	Constant Flow Air Break (30 LPM Actual Flow)
2.0 ATA	15.75 min	5.25 min
2.5 ATA	12.6 min	4.2 min
3.0 ATA	10.5 min	3.5 min

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This article has been reviewed and is acceptable for 1 Category A credit hours by the National Board of Diving and Hyperbaric Medical Technology.

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